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CODSTRAN: COMPOSITE DURABILITY STRUCTURAL ANALYSIS

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ABSTRACT

CODSTRAN (COmposite Durability STRuctural ANalysis) is an integrated computer program being developed for the prediction of defect growth and fracture of composite structures subjected to service loads and environments. CODSTRAN is briefly described herein with respect to organization, capabilities and present status. Application of CODSTRAN current capability to a flat composite laminate with a center slit which was subjected to axial tension loading predicted defect growth which is in good agreement with C-scan ultrasonic test records.

INTRODUCTION

Assessing and establishing the structural integrity and durability of composite structural components in service environments requires analysis capabilities which can reliably predict defect growth and fracture in these components. The defect in these components may be an initial flaw or it may be caused by stress concentrations. For quantitative predictions of defect growth and fracture in composite structural components the analysis capabilities should account for: complex component shapes, complex loading conditions (such as static, cyclic, dynamic and environmental), and material and geometric nonlinearities. In addition, the analysis capabilities should be relatively easy to use and update. These types of capabilities, by necessity, will be in the form of integrated computer programs. An integrated computer capability with many of the above features is under development at NASA Lewis Research Center (LeRC) under the acronym CODSTRAN (COmposite Durability STRuctural ANalysis). The objective of this paper is to provide a brief description of CODSTRAN with respect to its organization, capabilities, present status, and applications to date.

CODSTRAN

CODSTRAN is an integrated computer program designed to predict defect growth and fracture of composite structural components subjected to service load and environmental conditions. CODSTRAN is modular and open ended. Present modules may be replaced as improved ones becomes available and new ones can be added as they are developed. The organization (modular structure) of CODSTRAN, the function of its various modules and its capability are described in some detail in this section.

ORGANIZATION

The organization of CODSTRAN is shown schematically in the flow chart, figure 1. As can be seen in this figure CODSTRAN consists of seven major modules: Executive, Input, Output, Analysis, Composite Mechanics, Fracture Criteria, and Life Prediction. Communication between modules is through the Executive module. A brief description of the modules follows.

Executive module. The Executive module contains all the execution instructions of CODSTRAN and the communication links between the different modules. The user controls the program through the executive module. The logic flow of the execution instructions for defect growth and fracture, using Input (I/p), Output (O/p), the composite mechanics in MFCA (Multilayer Filamentary Composite Analysis Code (ref. 1)) and the structural/stress analysis in NASTRAN (ref. 2), is shown in figure 2. Note that the blocks are numbered in the upper left corner for convenience of reference. Each block in this diagram covers one or several execution instructions. For example: laminate fracture is identified in block 9 via the stability check; ply failure in block 20; failure mode in block 21; interply delamination in block 23; and defect growth in block 29. The crack opening displacement is calculated in block 12. The grid (node) coordinates and element stresses are updated in block 16. The load redistribution is accomplished by bypassing block 30 when defect growth has occurred.

Input module. The Input module (I/p) controls all the input including component geometry, defect geometry, composite type, laminate configuration, material properties, fracture data, fatigue data, and service environment. The input is expedited by using special purpose preprocessors (such as mesh generators) and computer resident data banks where composite data are compiled as they become available. The I/p module has provisions to activate available preprocessors and computer resident data banks. For example, the computer resident data bank for use with the MFCA is also available to CODSTRAN through the Input module. This data bank currently has properties for 14 different fibers, 10 different matrices, 10 different unidirectional composite systems, and 3 intraply hybrids.

Output module. The Output module (O/p) has the operational instructions for printing out the analysis results such as crack opening displacement, failed plies, fracture mode inducing failure, and defect growth. The output data are printed out in convenient tabular or graphical form for ease of interpretation. Additional and/or intermediate data may be printed out at the user's request. All the O/p features of NASTRAN are available.

Analysis modules. The Analysis modules planned for CODSTRAN consist of the following: (1) approximate analysis modules based mainly on the mechanics of materials methods; (2) fracture mechanics modules based on the $1/\sqrt{r}$ (r is the distance from the crack tip) near-field stress variation for slits and comparable ones for holes; (3) semi-empirical equations obtained by fitting strain gage data for the near field strain variation; (4) (4) special finite elements (hybrid singular element, ref. 3); and (5) NASTRAN (ref. 2). NASTRAN can be used for both the near- and far-field solution of large structures or structural components while the methods listed, items (2) to (4), are used only locally.

Composite mechanics module. The Composite Mechanics module consists mainly of the MFCA Computer Code (ref. 1). This code has composite micromechanics, composite macromechanics, combined stress failure criteria, linear and nonlinear laminate theories, and interply (interlaminar) failure (delamination) criteria. In addition, provisions are made for: (1) residual stress computations (ref. 4); (2) environmental (temperature and moisture) effect (ref. 5); (3) in situ ply strengths (ref. 6); and (4) free edge delamination due to interlaminar stresses using approximate relationships (ref. 7). The Composite Mechanics module is called several times during the analysis process. It is called to generate laminate properties for finite element analysis, compute ply and interply stresses, compute residual stresses, and check for ply and interply failures. Referring to figure 2, execution instructions calling for composite mechanics include blocks 3, 4, 18 to 24, 27 and 28.

Fracture Criteria module. The Fracture Criteria module is designed to accommodate static cyclic and dynamic fracture. The criteria for static fracture are of two forms: one for ply level fracture and the other for laminate fracture. The ply level fracture criteria are the two available in MFCA (ref. 1). One is based on a modified distortion energy principle and the other on a general quadratic surface fit. The interply fracture criteria used is that which is available in MFCA and is based on limiting the relative rotation of adjacent plies. The laminate level fracture criteria consist of the inherent flaw (refs. 9 and 10). In addition, provisions are available for several other fracture criteria such as the minimum strain energy density and combinations of linear elastic fracture mechanics modes I, II, and III (ref. 11).

Cyclic and dynamic fracture criteria are not available as yet. High-strain-rate experimental data currently being generated under a NASA contract will be used to develop approximate dynamic fracture criteria. Data from the literature are currently being examined to identify relevant cyclic failure criteria.

Life-Prediction module. The Life Prediction module will eventually provide the formalisms to predict the life and/or durability of a composite part under sustained load, fatigue, and service environments. No life prediction formalisms of this type are available as yet. The Wear-Out module (ref. 12) appears to be a step in this direction. Data currently generated under another NASA LeRC program will be used to develop life prediction criteria.

Capabilities

The functional features of the various modules will eventually provide CODSTRAN with the following capabilities:

1. Durability assessment of large structures and complex structural parts from composites,
2. Durability of components with regular and irregular defect geometry,
3. Accurate predictions of stress states near defects and discontinuities,
4. Structural response due to static, cyclic, transient impact and thermal loads,
5. Evaluation of defects in all types of fibrous composites and hybrids,
6. Assessment of environmental (temperature and moisture) effects on fibrous composites with defects,
7. Assessment of geometry and material nonlinearities on defect growth and fracture,
8. Criteria for static, cyclic and dynamic fracture,
9. Ply, interply and free-edge interlaminar failure criteria,
10. Predicting laminate level fracture when defects are present,
11. Predicting residual stress effects on defect growth,
12. Evaluating in situ ply strength effects on defect growth.

It is belived at this time that these capabilities are essential for reliably predicting the structural integrity of fibrous composite components and for assessing the associated durability.

Present Status

CODSTRAN is being developed at LeRC on the UNIVAC 1110 computer. The Executive module is almost completed for communication between the I/p, O/p, NASTRAN and MFCA modules. Some debugging, storage file and system associated difficulties exist in updating the solution from one load increment to the next after several cycles have been completed. At this stage of development, CODSTRAN has the following analysis capabilities:

1. Complex structural components, flaw geometry and load conditions - handled via NASTRAN available capabilities,
2. Composite mechanics - available in MFCA,
3. Static failures - ply-by-ply and intraply through MFCA,
4. All types of fibrous composites and several types of hybrids - handled through MFCA,
5. Lamination residual stresses - computed by MFCA,
6. Geometry and material nonlinearities - incorporate at the load increment following defect growth through NASTRAN and MFCA.

Even at this early stage of the development CODSTRAN has considerable capability for the prediction of defect growth and fracture in fibrous composite structures.

APPLICATION

CODSTRAN, with its present capability, has been applied to predict the defect growth in a flat specimen with a center through-slit and subjected to tension. The data used are from reference (13). The specimen geometry, composite system, and laminate configuration are shown in figure 3. This specimen has a width to crack-length ratio of about 5. The finite element model is shown in figure 4. The whole specimen was modeled in order to minimize the effects of displacement constraints that would have been required had advantage of symmetry been taken. The model consists of 530 plate elements (NASTRAN Library CQUAD2 and TRIAG2), 442 nodes (grid points) and 870 degrees of freedom (DOF). Two degrees of freedom per node are allowed for inplane loadings.

The variation of the stress σ_y predicted by CODSTRAN is plotted as a function of the distance "r" from the crack tip in figure 5. Two significant stress field characteristics in figure 5 are: (1) The normal stress varies inversely as the square root of the distance $(1/\sqrt{r})$ from up to $r/a = 0.7$ (2a is the crack length which corresponds to a distance of about two laminate thicknesses (0.4a) from the crack tip; and (2) the normal stress σ_y approaches thr gross stress σ_g at a distance of about four laminate thicknesses from the crack tip. Both of these observations illustrate thepoint that the stress concentration predominates in a relatively small region (about one laminate thickness) near the defect boundary.

CODSTRAN results of partial defect growth at 1000 pound intervals are shown in figures 6(a) to (h). In these figures, the initial crack is shown by the darkened squares. Element ply failures (locally damaged areas) are shown by the element outline, (open elements). In these elements any one or combinations of the following ply failures have occurred: transverse tension, intralaminar shear, fiber fractures, and interply delamination. Furthermore, these failures may have occurred in one or more plies or interply layers, but not in all the plies. A ply within the element has failed completely when it cannot carry additional load in any of the three fracture modes: longitudinal, transverse and intralaminar shear. An element has failed completely when all of its plies have failed completely. Complete element failure indicates defect growth (crack opening) and is depicted with the darkened elements in the computer plots.

As can be seen in figure 6(b) the two thousand pound load has caused ply failures in eight elements at the crack ends. Figures 6(c) to (f) show how ply failures progress away from the crack. The nonsymmetries seen in these figures are due to the tolerances (± 5 percent) allowed in the failure criteria. Figure 6(g) shows four complete element failures at eight thousand pounds. Note the extensive local ply failures shown in figure 6(h). The results in these figures taken collectively show that CODSTRAN and, therefore, the integrated theory it represents, predicts progressive failure and defect growth in composite laminates with defects.

C-Scan ultrasonic test records of the laminate prior to load (ref. 13) and at a load of about one-half the fracture load (11 000 lb) are shown in figure 7. This corresponds approximately to the damage growth predicted by CODSTRAN shown in figure 6(e). Figures 7(b) and 6(e) are shown in figures 8(a) and (b), respectively for comparison purposes. The undamaged part in figure 8(b) has been darkened to correspond to the C-Scan record (fig. 8(a)). It can be seen that the predicted results are in good qualitative agreement and are in reasonable quantitative agreement with the C-scan records. The predicted damage results (fig. 8(b)) are narrower and longer compared to the C-scan records (fig. 8(a)). The physical interpretation of this is that the predictions indicate less delamination damage and more transverse failure compared to the C-scan. The C-scan would not pick up the transverse failure readily since the record was made when the specimen was not under load.

The crack opening displacements predicted by CODSTRAN are also compared with those that were measured as shown in figure 9. As can be seen in this figure, CODSTRAN predicts somewhat smaller crack opening displacements compared to measured data. Though this may be considered as a reasonable agreement for the initial evaluation of CODSTRAN, it is clear that CODSTRAN needs additional refinements and tuning for improved quantitative correlations.

The results presented and discussed in this section demonstrate, in a limited way, some of the computational features, the potential, and the development status of CODSTRAN.

SUMMARY OF RESULTS

This paper presents a brief description of CODSTRAN (COmposite Durability STRuctural ANalysis), an integrated computer program under development at NASA Lewis Research Center. It is designed to predict defect growth and fracture of composite structures subjected to service loads and environments. When completed, CODSTRAN will account for geometry and material nonlinearities, environmental effects as well as static, cyclic and dynamic fracture. At thepresent state of development, CODSTRAN-predicted defect growth is in reasonable agreement with that observed in flat composite laminates with center slits and subjected to uniaxial tension.

REFERENCES

1. C. C. Chamis, "Computer Code for the Analysis of Multilayered Fiber Composites - Users Manual," NASA TN D-7013 (1971).

2. C. W. McCormick, ed., "NASTRAN User's Manual (level 15), NASA SP-222(01) (1972).

3. S. S. Wang and J. F. Mandell, "Analysis of Delamination in Unidirectional and Crossplied Fiber Composites Containing Surface Cracks," NASA CR-135248 (1977).

4. C. C. Chamis, "Residual Stresses in Angleplied Laminates and Their Effects on Laminate Behavior," NASA TM-78835 (1978).

5. C. C. Chamis, R. F. Lark and J. H. Sinclair, "An Integrated Theory for Predicting the Hydrothermomechanical Response of Advanced Composite Structureal Components," NASA TM-73812 (1977).

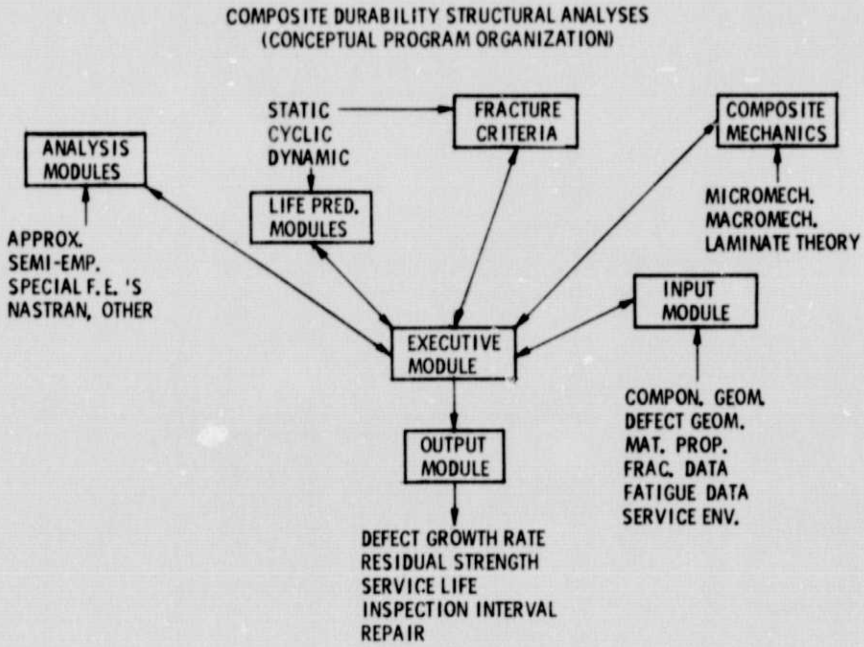


Figure 1. - Flow chart of CODSTRAN.

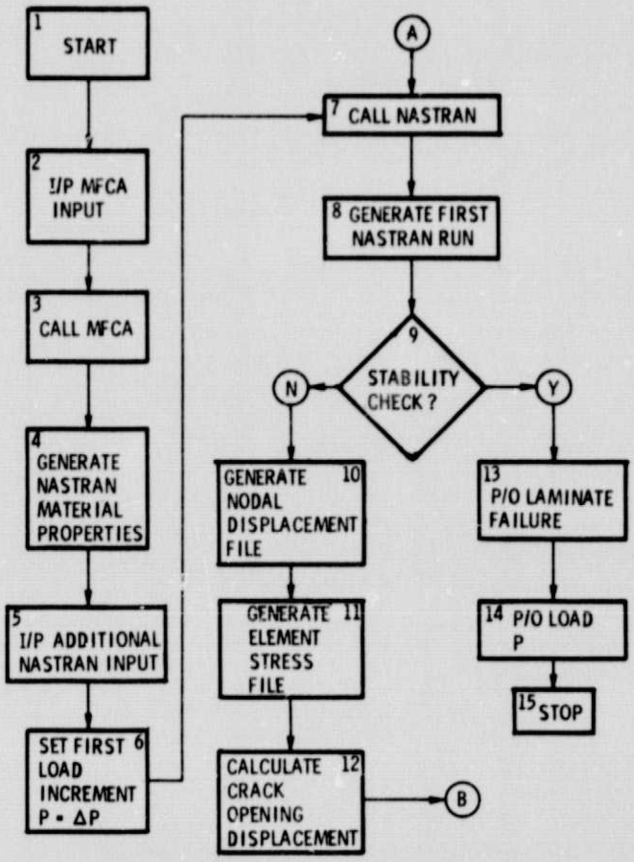


Figure 2. - CODSTRAN executive module flow chart.

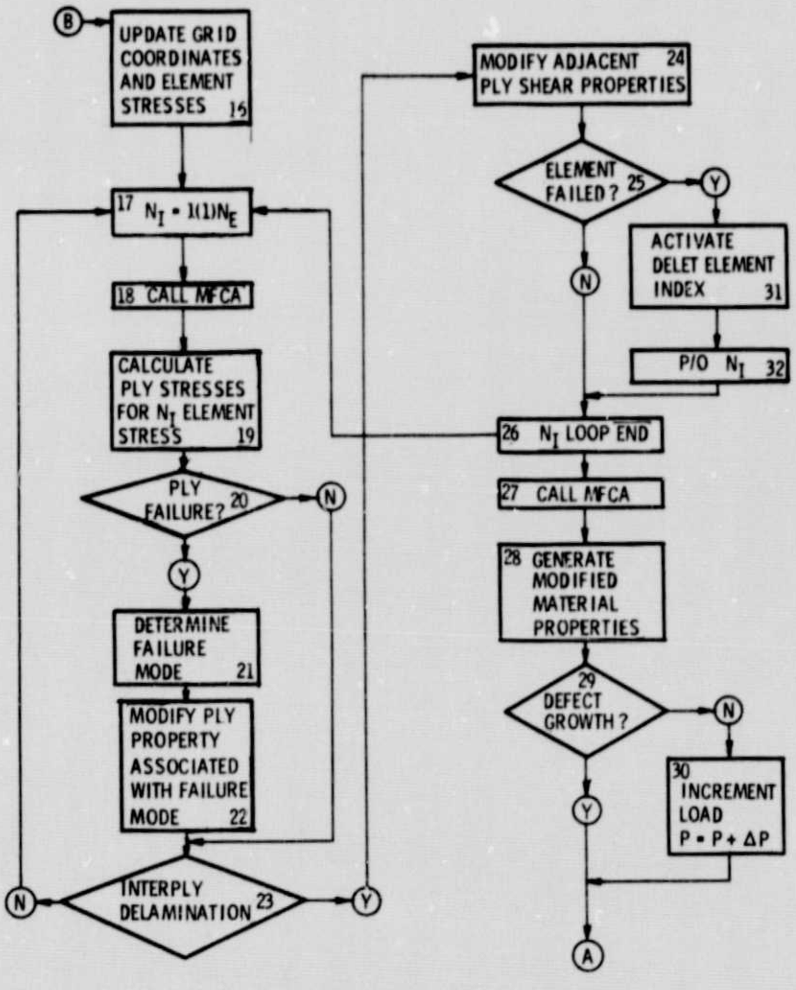


Figure 2 - Concluded.

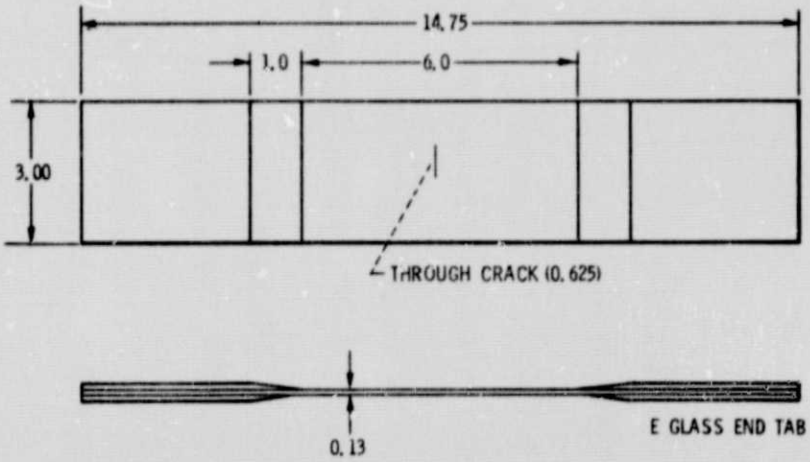


Figure 3. - Test specimen configuration. Graphite/epoxy (T300/5208) $[(0/+30/0/-30/0)_2]_s$, (dimensions inches).

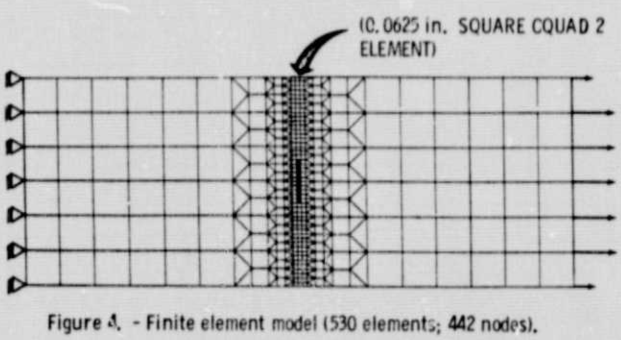


Figure 4. - Finite element model (530 elements; 442 nodes).

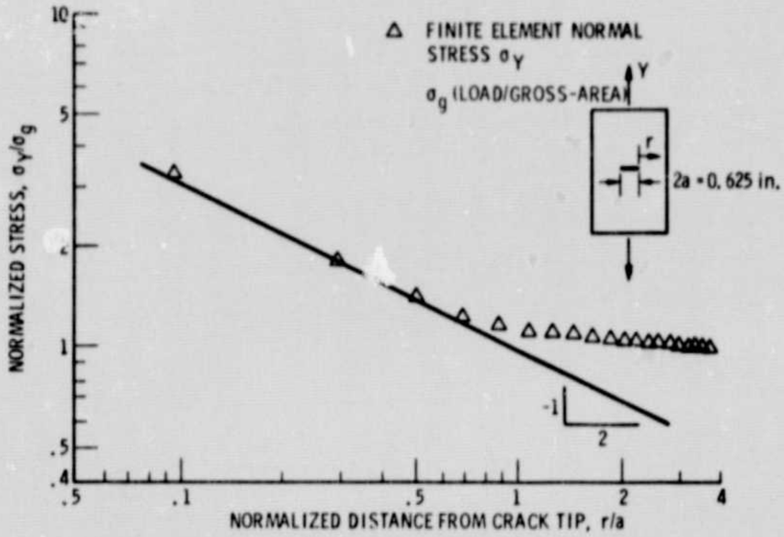
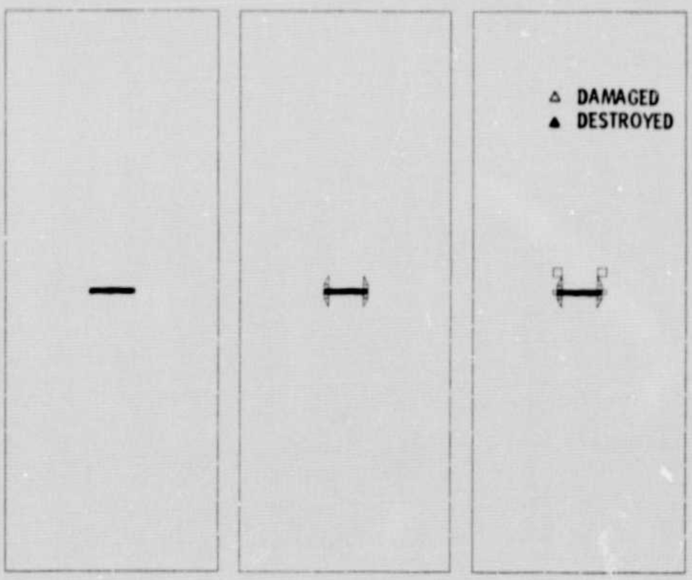
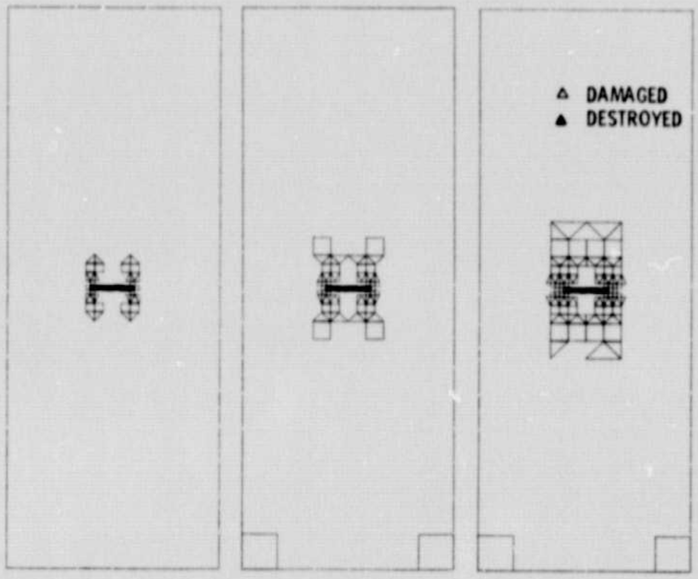


Figure 5. - Crack tip normal stress distribution. (Specimen geometry and laminate configuration, fig. 3.)



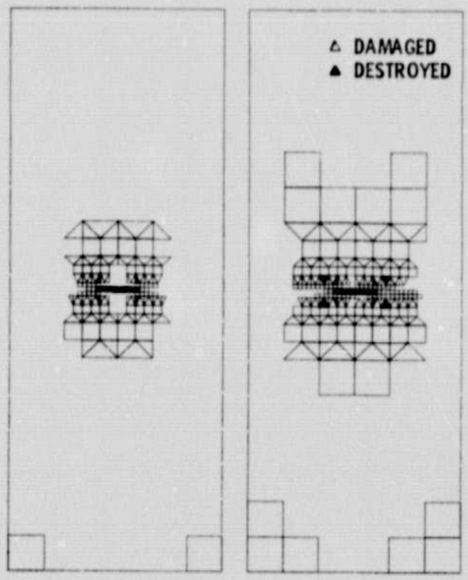
(a) LOAD = 1,000 lb. (b) LOAD = 2,000 lb. (c) LOAD = 3,000 lb.

Figure 6. - CODSTRAN predicted defect growth.



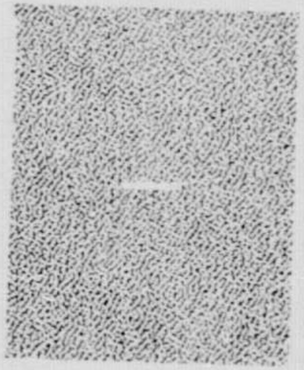
(d) LOAD = 4,000 lb. (e) LOAD = 5,000 lb. (f) LOAD = 6,000 lb.

Figure 6. - Continued.

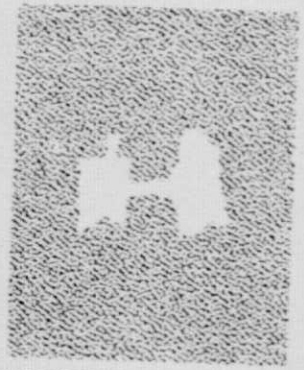


(g) LOAD = 7,000 lb. (h) LOAD = 8,000 lb.

Figure 6. - Concluded.

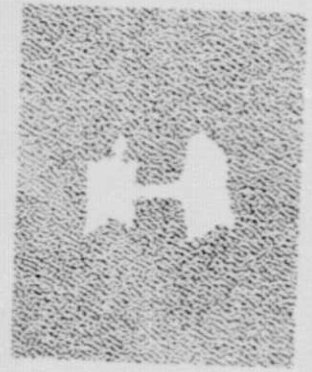


(a) NO LOAD.



(b) LOAD EQUAL APPROXIMATELY ONE-HALF FRACTURE LOAD.

Figure 7. - C-SCAN records of laminate with 5/8 in full penetration slit. (Specimen geometry and laminate configuration, fig. 3.)



C-SCAN RECORD

CODSTRAN

Figure 8. - C-SCAN/CODSTRAN defect growth comparisons (50 percent fracture load).

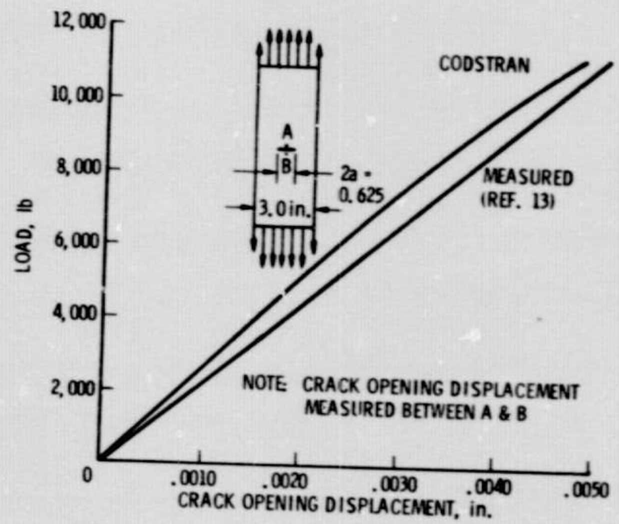


Figure 9. - Load vs. crack opening displacement in a graphite/epoxy laminate (T300/5208, $[(0/30/0/-30/0)_2]_s$).

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